Yeast Extract Production – Process Modeling and Techno-Economic Assessment (TEA) using SuperPro Designer

Preprint · August 2020

DOI: 10.13140/RG.2.2.27312.58882

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Yeast Extract production

Modeling and Evaluation with

SuperPro Designer®

by

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This is the ReadMe file of a SuperPro Designer example that deals with process modeling, cost analysis and optimization of Yeast Extract Production. The flowsheet of the process is appended to the bottom of this document. You may test-drive the model by downloading the functional evaluation edition of SuperPro Designer from the downloads page of our website (www.intelligen.com). The files of this example can be found in the **Examples \ Bio-Materials \ YeastExtract** folder. The default installation path of the SuperPro Designer Examples folder follows below.

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If you have any questions about this example and SuperPro Designer in general, please send an email message to dpetrides@intelligen.com

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Introduction

This example analyzes a yeast extract production process. Yeasts, as intact cells, are the most important and most frequently used microorganisms in the food industry (e.g. in bread-making). Yeast extract is also one of the most frequently used substrates in the fermentation industry, but also an ingredient in the food industry. Yeast cells consists of several macromolecules, mainly proteins but also nucleic acids (DNA and RNA), and complex carbohydrates. Each macromolecule offers a functionality to the cell. Yeast extract consists of cell contents of yeast without the cell walls. Some of the cell proteins are enzymes such as proteases and nucleases. These enzymes remain active after the inactivation of the cells. Under selected conditions, the proteases hydrolyze the remaining cell proteins to degrade them to peptides and even free amino acids. Similarly, nucleases degrade nucleic acids, DNA and RNA into nucleotides. Other enzymes degrade other macromolecules to more soluble substances. The smaller and more soluble molecules can then be extracted and separated from the yeast cell wall solid particles. The degradation of the macromolecules by the cell intracellular enzymes is called autolysis, and it is one of the most common methods to produce yeast extracts. Other methods include the addition of external enzymes for a faster or different cell components degradation. Yeast strains with a high protein content are preferred in order to have a product with high content in peptides and amino acids (Tanguler and Erten, 2009; Li *et al.*, 2015).

The carbon source for the fermentation is typically molasses or glucose syrup. The nitrogen source can be either organic or inorganic compounds. The yeast growth rate depends on the concentration of the carbon and nitrogen sources. Several other minerals and nutrients are added to enhance yeast growth. Fermentation is aerobic with typical aeration rates in the range of 0.5-1.0 volumes of air per volume of liquid per minute (VVM). Adequate agitation supports the aeration of the fermentation broth and reduces oxygen transfer limitations.

Yeast extract is marketed in various forms such as concentrated paste and powder. The flavor of yeast extract is primarily savory (a.k.a. *umami*). Key product properties include taste enhancement and the ability to partially replace salt. For this reason, it is used in the food industry as flavor enhancer in snacks, prepared meals, sauces and seasonings such as soy sauce, stock cubes and ketchup. Another major market is the animal feed industry (Anonymous a, 2020; Anonymous b, 2020). Other than peptides, free amino acids and nucleotides, yeast extract consists of carbohydrates, vitamins and minerals (ash). This mixture makes it a highly nutritive media and a perfect nitrogen substrate for fermentations, as it provides a mixture of components that facilitate microorganism growth. Yeast extract is used as a medium component in cell culture fermentations of industrial biotechnological processes but also of pharmaceutical bioprocesses to produce biologics.

The total global market for yeast products reached $5.8 billion in 2013. The largest part was the baker's yeast market, which reached $3.2 billion. The remaining $2.6 billion corresponded to all the remaining

yeast derived products, including yeast extract autolysates (Anonymous a, 2020). The total yeast market is expected to grow with a compound annual growth rate (CAGR) of around 7%. The main consumer of the global yeast market is the food and beverage industry, accounting for about 62% of the total market volume (Anonymous b, 2020). The expected market growth is mainly because of the growing demand of processed food, but also the growing fermentation industry.

Process Description

A conceptual process for yeast extract production was modeled and economically evaluated in SuperPro Designer to capture the expected stream flowrates, process equipment, utilities consumption and ultimately production costs. For reporting and analysis purposes, the process has been divided into four sections:

- Media Preparation
- Fermentation
- Yeast Separation and Autolysis
- Concentration and drying

Flowsheet sections in SuperPro are simply sets of related unit procedures (processing steps). For information on how to specify flowsheet sections and edit their properties, please consult Chapter 8.1 of the SuperPro manual. The contents of each of this example's flowsheet sections are described in greater detail below. The process will be easier to follow if you open this example within SuperPro and view the flowsheet while reading about the process. The flowsheet of the process is appended to the bottom of this document.

Media Preparation

The purpose of this section is to prepare the media used in the fermentation process. The fermentation relevant operating units (P-1 – P-4) operate in batch mode. The media preparation units, however, operate in continuous mode. The process starts with the preparation of the carbon substrate. The components are mixed in the Mixture Prep procedure P-5, and from there the substrate is sent to the agitated tank V-101. The mixture is continuously sterilized in P-7. The solution is preheated, then heated at a temperature of 140 °C, then cooled down against the inlet feed, and then cooled down to 37 °C with cooling water. The solution is then sent to V-102. From there it is distributed to all process users via the flow distributor FDIS-101. In parallel, fermentation water is sterilized, stored in V-104, and from there it is distributed to all process users via a flow distributor (FDIS-102). All tanks (V-101, V-102, and V-104) have a residence time of about 8 hours, which corresponds to the recipe cycle time (as it will be explained later, a new batch starts every eight hours). As such, each tank holds enough material to feed one batch.

Fermentation

This is the section of the conceptual process in which glucose syrup of 95.5% purity is fermented to expand the yeast culture. The fermentation section of the process operates in batch mode whereas the other sections are continuous. Batch mode was specified for the entire flowsheet to capture the scheduling links of the fermentation section. The inoculum is grown in a train of three seed fermentors (SFR-101, SFR-102 and SFR-103), which ultimately provide the inoculum to the main fermentors (FR-101). The fermentation time of all the fermentors is 48 hours. During fermentation, oxygen is supplied by a compressor (G-101). The air is filtered in AF-101, compressed in G-101, cooled down at 37 °C in cooler HX-101 against cooling water, and distributed to the users via the flow distributor FDIS-103. The stoichiometry of the main fermentation reaction follows:

10 Diammonium Phosphate + 100 Glucose + 70 Oxygen →
100 Carbon Dioxide + 15 Water + 65 Yeast

The extent of the reaction was set at 98%. Glucose syrup contains sugars other than glucose, namely maltose, maltotriose and traces of DPn (polymers with more than three glucoses). All of these are ultimately fermented.

The three seed fermentors and the main fermentor include the following operations:

- SIP (Steam-In-Place). At the beginning of each batch a SIP operation ensures sterility of the vessels and piping, prior to pulling in the substrate, water, and inoculum.
- Pull-In Substrate. Right after the SIP, the correct amount of substrate is pulled into the sterilized vessel
- Pull-In Water. The correct amount of water is pulled into the vessel. This was set by visiting the Operation Data dialog, selecting “Set by Other specification”, and in the Setup dialog that pops up, “Set Composition of Component” Water at 88%
- Pull-In Inoculum. In the seed train, the broth of the previous fermentation step inoculates the next fermentor. The first seed fermentor is inoculated by a vial or a shake flask. The inoculation ratio, meaning the weight of inoculum divided by the weight of the media, was assumed to be about 10%.
- Ferment. As soon water, substrate and inoculum are in the fermenter, the fermentation starts. Air is supplied at a rate of 0.5 VVM. The temperature is assumed to be maintained at about 37 °C. The heat generated by the fermentation, which was assumed to be 3,700 kcal/kg O_2, is removed by cooling water.
- Transfer-Out. At the end of fermentation, the broth of each fermentor is sent to the next fermentor to inoculate it. The broth of the main fermentor is transferred into a feed buffer tank, V-105
- CIP. After the end of each fermentation and the transfer of the broth, the vessel is cleaned in place.

For each fermentation step there are 8 equipment units operating in staggered mode. Each fermentation takes 48 hours. Since the quantity of broth of each fermenter is different, there are differences in the time required for pulling in the media and transferring out of the broth. Ultimately, the main fermentation, having the largest quantity of broth, is the bottleneck of the process, with a procedure duration of 61.50 h. A new batch can thus be started every 8 hours. Assuming that the plant operates 49 weeks per year, the total number of batches per year is 1,001.

Yeast Separation and Autolysis

As explained above, the Fermentation section operates in batch mode, whereas the rest of the process operates in continuous mode. The broth of the production fermentor is transferred from FR-101 to V-105. The residence time in V-105 was set at 8 hours, which is equal to the recipe cycle time. This allows tank V-105 to be sized to be capable of holding the broth of one batch. The broth is then sent to the pasteurizer PZ-103. In there the slurry is preheated by the hot outlet slurry, which needs to be cooled down, then heated at 75 °C, then cooled to 43 °C against the inlet cold stream, and then cooled down to 40 °C against cooling water. This inactivates the yeast cells, without considerably damaging the intracellular enzymes. The cells are then separated from the solution broth using a disk-stack centrifuge (DS-101). The solids concentration in the underflow of DS-101 was set at 650 g/L. The overflow (supernatant) is sent to the mixer P-21 and from there to the wastewater treatment. The cells are washed by adding recycled process water (the origin of the recycled water will be later analyzed) in the custom mixer MX-102, and then centrifuged again in DS-102. The solids concentration in the underflow of DS-102 was set at 650 g/L. The overflow is mixed in P-21, together with the overflow from the first centrifugation and sent to the wastewater treatment. The cells in the underflow (heavy phase or solids) are sent for autolysis in R-101. Reactor R-101 operates in batch mode and cycles independently of the main recipe. It includes the following operations:

- Pull-In. The underflow of the second centrifuge DS-102 is collected over a period of 24 hours
- Heat 1. The cell slurry is heated to 50 °C.
- React. The autolysis starts and lasts for about 24 hours. The temperature is maintained at 50 °C. The heat of reaction is removed using cooling water.
- Heat 2. To initiate the enzymes inactivation, the slurry is heated to 80 °C against steam.
- Hold. The slurry is kept at a high temperature for about 30 minutes.
- Cool 1. The slurry is cooled down to 40 °C using cooling water.
- Transfer-Out. The vessel is emptied over a period of 24 hours, feeding the DS-103 centrifuge.

The autolysis reaction has the following stoichiometry:

100 Yeast → 12.5 Ash + 12.5 Carbohydrates + 25 Cell Wall + 50 Peptides

The extent of the reaction was set at 100%.

Concentration and Drying

The slurry is centrifuged in DS-103, which separates the autolyzed yeast extract from the cell walls (or cell debris). The solids concentration in the underflow of DS-103 was set at 300 g/L. The underflow of the centrifuge is dried in a rotary dryer (RDR-101). The final moisture content was set at 10%. The dryer uses steam as heating agent and the drying operation includes a cooling step, which uses air to cool down the powder. The final yeast cell powder has a temperature of 30 °C. The overflow of the DS-103 centrifuge contains all the soluble yeast extract. It is concentrated in a two-stage evaporator (EV-101) to a final dry solids concentration of about 65%. It is then dried in a spray dryer (SDR-101) to a water content of about 11%, and then the powder is cooled down with air in RDR-102. The vapor of the second stage of the evaporator is condensed (HX-102) and then it is combined with the condensate of the first stage in a mixer (MX-104). The total condensate is pumped through PM-101 and cooled down to 31 °C in HX-103. It is then recycled back to the cell harvest wash in MX-102 via the Flow Adjustment procedure FAD-101. Fresh water is also added in the loop at this unit.

Note that both centrifuges DS-101 and DS-102 in the Yeast Separation and Autolysis section were set to have a solids concentration of 650 g/L in the underflow. The high solids concentration represents the wet cell mass. However, after autolysis, the third disc stack centrifuge (DS-103) in the Concentration and Drying section, was set to have a lower solids concentration of 300 g/L. This is because after autolysis the chemical composition of the slurry has changed and does not include intact cells, which contain intracellular water. Details on how to specify intracellular water for bioprocesses are provided in the Miscellaneous Modeling Tips section of the **Itaconic Acid** example readme file, which can be found in the Examples \ Bio-Materials subfolder.

Economic Evaluation

This plant produces about 9,200 MT of autolyzed yeast extract per year, with an assumed annual operating time of 8,208 hours per year, corresponding to 49 weeks per year. Various assumptions were made for the costs of raw materials, heat transfer agents, wastewater treatment, equipment purchase costs, labor *etc*. In addition to the mass and energy balances, SuperPro Designer calculates the capital (CAPEX) and operating expenses (OPEX), the production cost and the profitability of the project. The results can be found in the Economic Evaluation (EER), Cash Flows Analysis (CRF), Itemized Cost (ICR) and Excel Custom reports. **Table 1**, which was extracted from the ERR and is shown below, provides information on equipment sizes and purchase costs. The SuperPro Designer built-in cost models were used for estimating the purchase cost of most equipment. User-defined cost models were used for estimating the purchase cost of the compressor, tanks and the seed and main fermenters. The specification of User-defined cost models are explained in detail in the manual and in the corn refinery example ReadMe file. **Table 2**, which was also extracted from the ERR, provides an estimate of the Direct Fixed Capital Cost, which is around $60 million for a plant of this capacity.

1. MAJOR EQUIPMENT SPECIFICATION AND FOB COST (2020 prices)

Quantity/ Standby/ Staggered	Name	Description	Unit Cost ($)	Cost ($)
1 / 0 / 0	G-101	Centrifugal Compressor Compressor Power = 1852.77 kW	774,000	774,000
1 / 0 / 0	PZ-102	Pasteurizer Rated Throughput = 17234.28 L/h	595,000	595,000
1 / 0 / 0	EV-101	Multi-Effect Evaporator Mean Heat Transfer Area = 71.11	579,000	579,000
1 / 0 / 7	FR-101	Fermentor Vessel Volume = 233797.65 L	529,000	4,232,000
1 / 0 / 2	R-101	Stirred Reactor Vessel Volume = 252139.21 L	478,000	1,434,000
1 / 0 / 0	RDR-101	Rotary Dryer Drying Area = 67.22 m2	427,000	427,000
1 / 0 / 0	DS-101	Disk-Stack Centrifuge Throughput = 23437.07 L/h	314,000	314,000
1 / 0 / 0	PZ-101	Pasteurizer Rated Throughput = 6986.77 L/h	277,000	277,000
1 / 0 / 0	DS-102	Disk-Stack Centrifuge Throughput = 16226.47 L/h	261,000	261,000
1 / 0 / 0	PZ-103	Pasteurizer Rated Throughput = 23379.76 L/h	214,000	214,000
1 / 0 / 0	DS-103	Disk-Stack Centrifuge Throughput = 9338.75 L/h	198,000	198,000

1 / 0 / 0	V-105	Blending Tank	174,000	174,000
		Vessel Volume = 267197.31 L		
1 / 0 / 0	SDR-101	Spray Dryer	163,000	163,000
		Dryer Volume = 8605.21 L		
1 / 0 / 0	AF-101	Air Filter	143,000	143,000
		Rated Throughput = 36108673.55		
1 / 0 / 0	V-104	Blending Tank	134,000	134,000
		Vessel Volume = 172849.55 L		
1 / 0 / 7	SFR-103	Seed Fermentor	133,000	1,064,000
		Vessel Volume = 23305.48 L		
1 / 0 / 0	V-102	Blending Tank	78,000	78,000
		Vessel Volume = 70085.80 L		
1 / 0 / 0	V-101	Blending Tank	78,000	78,000
		Vessel Volume = 69842.83 L		
1 / 0 / 0	HX-103	Heat Exchanger	60,000	60,000
		Heat Exchange Area = 29.48 m2		
1 / 0 / 0	HX-102	Condenser	55,000	55,000
		Condensation Area = 207.98 m2		
1 / 0 / 0	HX-101	Heat Exchanger	49,000	49,000
		Heat Exchange Area = 20.98 m2		
1 / 0 / 0	RDR-102	Rotary Dryer	37,000	37,000
		Drying Area = 4.72 m2		
1 / 0 / 7	SFR-102	Seed Fermentor	31,000	248,000
		Vessel Volume = 2025.56 L		
1 / 0 / 0	PM-101	Centrifugal Pump	11,000	11,000
		Pump Power = 0.26 kW		
1 / 0 / 7	SFR-101	Seed Fermentor	6,000	48,000
		Vessel Volume = 107.97 L		
		Unlisted Equipment		2,055,000
			TOTAL	13,698,000

2. FIXED CAPITAL ESTIMATE SUMMARY (2020 prices in $)

3A. Total Plant Direct Cost (TPDC) (physical cost)	
1. Equipment Purchase Cost	13,698,000
2. Installation	4,735,000
3. Process Piping	2,740,000
4. Instrumentation	2,740,000
5. Insulation	411,000
6. Electrical	1,370,000
7. Buildings	2,740,000
8. Yard Improvement	1,370,000
9. Auxiliary Facilities	2,740,000
TPDC	32,541,000

3B. Total Plant Indirect Cost (TPIC)	
10. Engineering	8,135,000
11. Construction	11,390,000
TPIC	19,525,000

3C. Total Plant Cost (TPC = TPDC+TPIC)	
TPC	52,066,000

3D. Contractor's Fee & Contingency (CFC)	
12. Contractor's Fee	2,603,000
13. Contingency	5,207,000
CFC = 12+13	7,810,000

3E. Direct Fixed Capital Cost (DFC = TPC+CFC)	
DFC	59,876,000

Tables 3a,b,c provide information on the assumed unit costs and the calculated annual amounts and costs for a) raw materials, b) labor and c) utilities. The total annual cost of raw materials was calculated to be around $12.3 million per year. According to **Table 3b** the cost of labor was estimated at around $7.1 million per year. **Table 3c** displays the utilities costs, which were estimated to be about $5.6 million per year.

3a. MATERIALS COST - PROCESS SUMMARY

Bulk Material	Unit Cost	Annual	Annual Cost	%
Air	0.00	808,311,170kg	0	0.00
Diammonium Phos	0.15	3,026,774kg	454,016	3.69
DPn	0.50	60,340kg	30,170	0.25
Glucose	0.50	21,187,416kg	10,593,708	86.04
Maltose	0.50	527,393kg	263,696	2.14
Maltotriose	0.50	387,015kg	193,507	1.57
NaOH (2%)	0.01	3,560,434kg	21,078	0.17
Soluble Protein	0.00	2,653kg	0	0.00
Solubles	0.00	1,342kg	0	0.00
Water	4.00	189,021MT	756,084	6.14
Yeast	2.30	70kg	161	0.00
TOTAL			12,312,421	100.00

NOTE: Bulk material consumption amount includes material used as:

- Raw Material

- Cleaning Agent

3b. LABOR COST - PROCESS SUMMARY

Labor Type	Unit Cost	Annual Amount	Annual Cost	%
Operator	69.00	102,701	7,086,345	100.00
TOTAL		102,701	7,086,345	100.00

3c. UTILITIES COST (2016 prices) - PROCESS SUMMARY

Utility	Unit Cost	Annual	Ref.	Annual Cost	%
Std Power	0.10	27,798,387	kW-h	2,779,839	49.84
Steam	30.00	60,592	MT	1,817,753	32.59
Cooling Water	0.05	19,607,804	MT	980,390	17.58
TOTAL				5,577,982	100.00

Figure 1 provides a breakdown of the total annual operating costs. Clearly raw materials, facility-dependent (depreciation of the capital investment, maintenance, etc.) and labor costs have the highest contribution to the total annual operating costs, at 32%, 30% and 18% respectively. Finally, **Table 4** provides an executive summary. The total CAPEX required was estimated to be about $65 million. If the selling price of yeast extract and yeast cell powder is set at $4/kg and $1.5/kg respectively, the expected payback time is around 6.3 years.

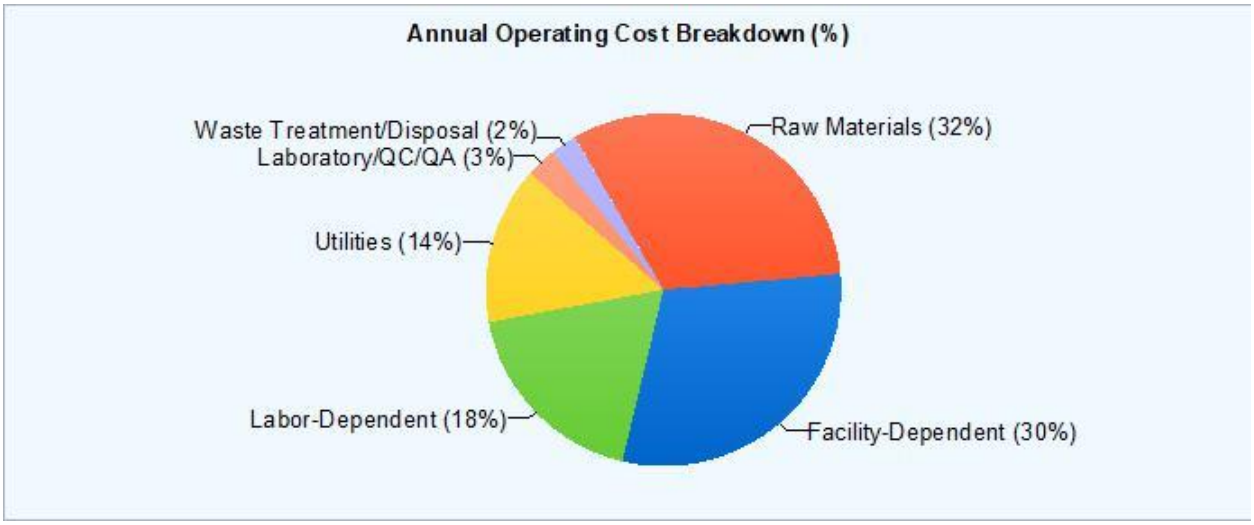

Figure 1: Annual Operating Cost Breakdown (%)

5. EXECUTIVE SUMMARY (2020 prices)

Total Capital Investment	65,144,000 $
Capital Investment Charged to This Project	65,144,000 $
Operating Cost	38,610,000 $/yr
Main Revenue	36,896,000 $/yr
Other Revenues	9,413,522 $/yr
Total Revenues	46,309,000 $/yr

Batch Size	9,214.67 kg MP
Cost Basis Annual Rate	9,223,883 kg MP/yr
Unit Production Cost	4.19 $/kg MP
Net Unit Production Cost	4.19 $/kg MP
Unit Production Revenue	5.02 $/kg MP
Gross Margin	16.63 %
Return On Investment	15.82 %
Payback Time	6.32 years
IRR (After Taxes)	8.88 %
NPV (at 7.0% Interest)	17,602,000 $

MP = Total Flow of Stream 'Yeast Extract Powder'

Summary

Our objective with this example was to present a simple yeast extract production model in SuperPro Designer that is easy to understand and follow. As indicated by the preceding analysis, a plant with capacity of about 9,200 metric tons of yeast extract per year requires a total CAPEX of around $65 million and annual operating expenditures (including depreciation) of around $38.6 million. The predominant cost is the cost of raw materials, especially the 95.5% glucose syrup, followed by the facility-dependent costs. The payback time of this investment was estimated to be about 6.3 years. Several advanced modeling features of SuperPro Designer were exhibited and discussed.

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